

# Energy loss of partons traversing a QGP fluid

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We analyse the azimuthal correlation function for high  $p_T$  charged hadrons in Au+Au collisions at the RHIC energy. By using a dynamical model in which hydrodynamics is combined with explicit propagation of high  $p_T$  partons, we study the effect of the intrinsic transverse momentum of initial partons on the azimuthal back-to-back correlations.

## 1. INTRODUCTION

Measurements of high  $p_T$  hadrons at the Relativistic Heavy Ion Collider (RHIC) may provide insight into a quark gluon plasma (QGP) [1]. Since jets have to traverse the excited matter, their spectra should be changed in comparison with the elementary hadron-hadron data. The energy loss of jets has been proposed as a possible signal of the QGP phase in relativistic heavy ion collisions [2]. Over the past year, a lot of work have been devoted to study the propagation of jets through QCD matter [3].

Recently, hadronic transverse momentum distributions in Au + Au collisions at  $\sqrt{s_{NN}} = 130$  and 200 GeV have been measured at RHIC and found that the yield of hadrons is suppressed at high transverse momentum [4,5]. These data are consistent with the picture in which jets considerably lose their energy in hot/dense medium. In addition, the magnitude of the away-side jets is found to be significantly suppressed in comparison with the near-side jets in central collisions from the azimuthal correlation measurements at high  $p_T$  [6]. The disappearance of the away-side peaks in central collisions implies that the one jet can escape from medium and the other correlated jet is absorbed by medium [7].

On the other hand, a novel hydrodynamical calculation, in which the early chemical freeze-out is taken into account, show that the  $p_T$  slope for pions is insensitive to thermal freeze-out temperature  $T^{\text{th}}$  [8] and that the hydrodynamical result starts to deviate from the experimental data at  $p_T = 1.5\text{-}2.0$  GeV/ $c$ . See Fig. 1. This result naturally leads us to include the mini-jets component in addition to the hydrodynamic component.

Thus, we developed the hydro+jet model in which a full three dimensional space-time evolution of a fluid is combined with explicit propagation of jets [9]. The hydro+jet model enables us to estimate the *dynamical* effect of hot matter on the parton energy loss in relativistic heavy ion collisions. By using this model, we study the azimuthal correlation functions at the RHIC energy.

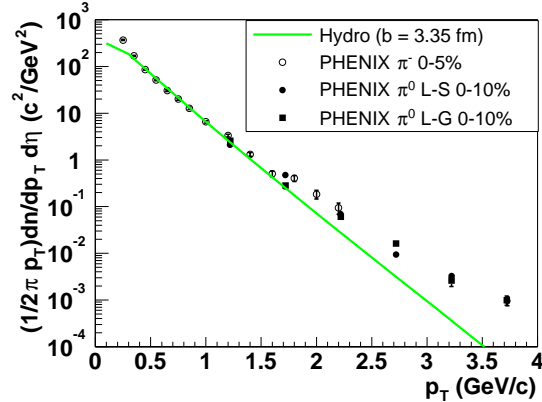


Figure 1. The transverse momentum spectrum from a hydrodynamic model including the effect of early chemical freeze-out is compared with the compiled PHENIX data in Au+Au collisions at  $\sqrt{s_{NN}} = 130$  GeV.

## 2. MODEL

We have already had a hydrodynamic solution which reproduces the experimental data in the low  $p_T$  region ( $p_T \lesssim 1.5$  GeV/c) at the RHIC energy. For details on initialization of fluids, treatment of the early chemical freeze-out and its consequences used in this calculation, see Ref. [8].

We include hard partons (defined by particles that have transverse momentum greater than 2 GeV/c just after initial collisions) using pQCD parton model. The spectrum of hard partons per hard collision before traversing hot matter can be written as

$$E \frac{d\sigma_{\text{jet}}}{d^3p} = K \sum_{a,b} \int g(k_{T,a}) d^2k_{T,a} g(k_{T,b}) d^2k_{T,b} f_a(x_1, Q^2) dx_1 f_b(x_2, Q^2) dx_2 E \frac{d\sigma_{ab}}{d^3p}, \quad (1)$$

where  $f$  and  $g$  are the collinear and transverse parts of parton distribution function,  $x$  is the fraction of longitudinal momentum and  $k_T$  is the transverse momentum of initial partons in a nucleon. A factor  $K$  is used for the higher order corrections. The collinear parton distribution functions  $f_a(x, Q^2)$  are taken to be CTEQ5 leading order [11]. Gaussian distribution function  $g$  for primordial transverse momentum  $k_T$  with the width of  $\langle k_T^2 \rangle = 1$  GeV<sup>2</sup>/c<sup>2</sup> is assigned to the shower initiator in the QCD hard  $2 \rightarrow 2$  processes. We use PYTHIA 6.2 [12] to simulate each hard scattering and initial and final state radiations in the actual calculation. In order to convert hard partons into hadrons, we use an independent fragmentation model in PYTHIA after hydrodynamic simulations. We have checked that this hadronization model with  $K = 2$  provides good agreement with the transverse spectra of charged hadrons in  $p\bar{p}$  collisions [13] and of neutral pions in  $pp$  collisions above  $p_T = 1$  GeV/c at  $\sqrt{s} = 200$  GeV [14].

The number of hard partons is assumed to scale with the number of hard scattering which is estimated by using Woods-Saxon nuclear density. The transverse coordinate of a parton is specified by a distribution being proportional to the number of binary collision.

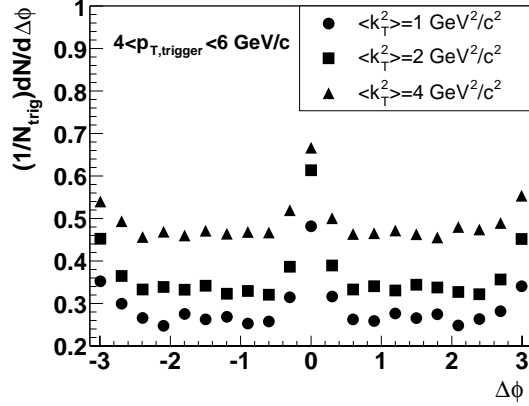


Figure 2. Two-particle azimuthal correlation function for charged particles in Au+Au 200A GeV central collisions. Circle, square and triangle plots correspond to  $\langle k_T^2 \rangle = 1, 2$  and  $4 \text{ GeV}^2/c^2$  respectively.

We assume that partons move along a straight path and lose their energy throughout traversing partonic medium. We here use the following formula for parton energy loss

$$\Delta E = C \int_{\tau_0}^{\tau_f} d\tau (\tau - \tau_0) \rho(\tau, \mathbf{x}(\tau)) \ln \left( 1 + \frac{2E}{\mu^2 R_{\text{Au}}} \right). \quad (2)$$

Here  $\rho$  is a thermalized parton density from hydrodynamic simulation. The screening mass  $\mu$  is taken to be a typical value  $0.5 \text{ GeV}$ . The coefficient  $C (= 0.25)$  is chosen so that the suppression factor  $R_{AA}$  at  $p_T = 3 \text{ GeV}/c$  becomes the same value as the one for the incoherent parton energy loss model discussed in the previous work [9]. When the parton density is static, the above formula shows the same medium length dependence as the BDMPS formula ( $\propto L^2$ ) [10].

### 3. RESULTS

Figure 2 shows the two-particle azimuthal correlation function of charged hadrons in midrapidity region ( $|\eta| < 0.7$ ) in Au+Au central collisions at  $\sqrt{s_{NN}} = 200 \text{ GeV}$ . Here charged hadrons in  $4 < p_{T,\text{trigger}} < 6 \text{ GeV}/c$  and in  $2 < p_{T,\text{associate}} < p_{T,\text{trigger}} \text{ GeV}/c$  are defined to be trigger particles and associated particles respectively. We neglect the contribution from soft (hydro) components which, in central collisions, does not affect the relative strength between the near-side peak ( $\Delta\phi = 0$ ) and the away-side peaks ( $\Delta\phi = \pm\pi$ ). The away-side peaks do not vanish even when the parton energy loss and the intrinsic transverse momentum  $\langle k_T^2 \rangle = 1 \text{ GeV}^2/c^2$  are taken into account. Since the initial multiple scattering inside colliding nuclei releases the constraint of exact back-to-back kinematics, we estimate its effect on the azimuthal correlation function. This effect can be parametrized phenomenologically by increasing  $\langle k_T^2 \rangle$ . We also represent the results for  $\langle k_T^2 \rangle = 2$  and  $4 \text{ GeV}^2/c^2$  in Fig. 2. The away-side peaks are found to be slightly

weaken as  $\langle k_T^2 \rangle$  increases. Nevertheless, we can still see the away-side peaks. Therefore our results indicates that, in addition to parton energy loss in hot medium and intrinsic  $k_T$  of partons in nuclei, another mechanism is needed to obtain the disappearance of back-to-back correlations

#### 4. SUMMARY AND DISCUSSION

We have studied the effect of intrinsic  $k_T$  of partons in a nucleus on the final azimuthal correlations of high  $p_T$  hadrons by using the hydro+jet model. We found that the parton energy loss which is chosen so as to quantitatively reproduce the suppression factor  $R_{AA}$  is insufficient for vanishing the back-to-back correlations and that even a large  $\langle k_T^2 \rangle$  ( $= 4 \text{ GeV}^2/c^2$ ) does not result in the disappearance of the away-side peaks.

The parton energy loss is related to the  $p_\perp$  broadening of jets in hot/dense medium [15]. During propagation, jets can get transverse momentum orthogonal to its direction of motion. As a consequence, these partons follow zig-zag paths in hot medium. This is naturally expected to affect the back-to-back correlation of jets. The effect of  $p_\perp$  broadening on the azimuthal correlation function of high  $p_T$  hadrons will be discussed elsewhere [16].

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